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Modeling the formation of undulations of the coastline: The role of tides

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Abstract

An idealized model is developed and analyzed to investigate the relevance of tidal motion for the emergence of undulations of a sandy coastline. The model describes feedbacks between tidal and steady flow on the inner shelf, sand transport in the nearshore zone and an irregular coastline. It is demonstrated that an initially straight coastline can become unstable with respect to perturbations with a rhythmic structure in the alongshore direction. The mechanism causing the growth of these perturbations is explained in terms of vorticity concepts. The relative importance of tide-related and wave-driven sediment fluxes in generating undulations of the coastline is investigated for the Dutch coast. Using parameter values that are appropriate for the Dutch coast it is found that tides can render a straight coastline unstable. The model predicts a fastest growing mode (FGM) with a wavelength that is in the order of the observed length of barrier islands. The mode grows on a time scale of 50 yr and it migrates 200 m per year. The wavelength of the FGM decreases with increasing amplitude of the tidal currents. This result is consistent with data of tides, waves and the lengths of barrier islands that are located along the Dutch and German Wadden coast.

Keywords: Coastal morphology; Barrier Island; Tidal currents; Wadden Sea

1. Introduction

A large part of the world's sandy coastlines shows alongshore rhythmic variations on a wide range of length and time scales (Ehlers, 1988; Komar, 1998). This paper focuses on rhythmic mesoscale variations of sandy coasts, i.e., with a characteristic length scale in the alongshore direction of a few kilometers to tens of kilometers. Such mesoscale variations include shoreline sand waves (Bruun, 1954; Thevenot and Kraus, 1995; Ruessink and Jeuken, 2002) and sequences of barrier islands along the Dutch, German and Danish Wadden coast (Fig. 1). Here, the typical length of the barrier islands ranges between a few kilometers (Rottumeroog) and 30 km (Texel). It has been noted that the typical length of the barrier islands is inversely related to the tidal range (Oost and de Boer, 1994).

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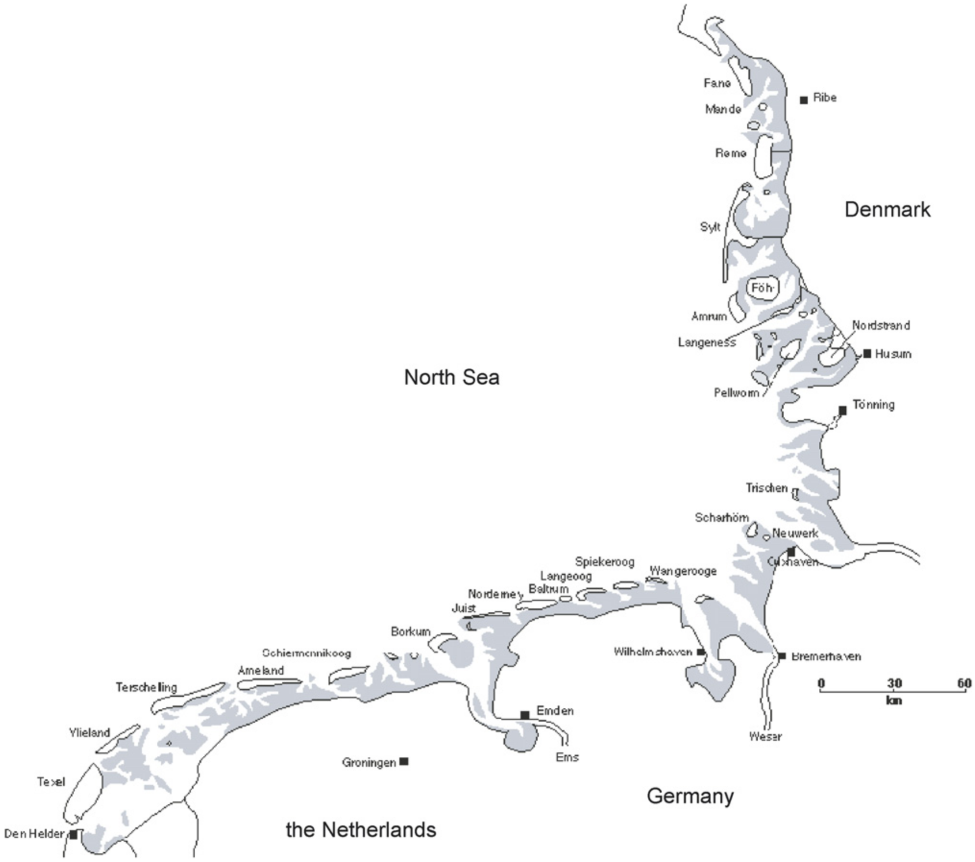

Fig. 1. Map showing the barrier islands along the Dutch, German and Danish Wadden coast.

The tidal range increases when moving from the Dutch Wadden Sea towards the German Bight. A similar relation between tidal range and the length of the barrier islands is found for other barrier coasts, e.g., that of Georgia Bight at the east Atlantic coast of the USA (FitzGerald, 1996).

The general objectives of the present study are twofold. The first is to gain fundamental knowledge about the origin of the observed rhythmic mesoscale variations of the coastline. The second is to derive a quantitative relationship between the characteristic length of these undulations and physical control parameters (like tidal, wave and shelf characteristics). In the past, several models were developed to analyze the dynamics of coastlines which are influenced by waves. They are all one-line models, i.e., the complex three-dimensional dynamics is parameterized, resulting in an equation for the coastline position only. A widely used one-line model is the one described by Komar (1998) (originally from Pelnard-Considère, 1956). It is based on the idea that obliquely incident waves break in the surf zone and drive a current which transports sediment. Alongshore variations in this sediment transport result in changes of the position of the coastline. Upon assuming that the width of the surf zone is constant and by only considering small deviations of the position of the coastline with respect to its alongshore mean, a diffusion equation for the position of the coastline is obtained. The diffusion coefficient is a function of the wave characteristics at the breaker line and the angle between the direction of the wave rays at breaking and the normal of the local (unperturbed) coastline. A positive (negative) diffusion coefficient implies that a small initial perturbation of the coastline will decay (grow). A negative diffusion coefficient is obtained when the angle between wave rays at breaking and the normal of the local coastline is more than 45°.

The traditional one-line model was extended by Ashton et al. (2001) and Falqués (2003). They